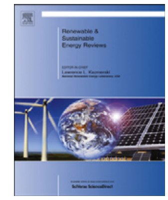
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Regional differentiation of biogas industrial development in China

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ABSTRACT

The regional distribution of household biogas and large & medium-scale farm biogas project was analyzed by the index of popularization rate. The results showed that Chinese household biogas has an obvious geographical difference in popularization rate, and can be divided into five zones: high popularity in Southwest areas, steady development in Central areas, rapid growth in Western areas, and low popularity in Northeast and Eastern coastal areas. The emphasis of household biogas development was shifted from east to west, which was mainly caused by combined effects of climatic conditions and economic level. The popularization rate of large & medium-scale biogas project in livestock farms was low, but developed rapidly with average annual increasing rate of 13.94%. And great differentiation existed in popularization rate and growth trends, of which 98.63% of running biogas project and 94.5% of digester capacity were located in southern areas to demarcation line constituted by boundaries of Liaoning, Hebei, Shanxi, Shaanxi, Gansu and Sichuan. Two-way growth in amount and growth trend was shown in southeast coast and southwest regions, while unidirectional growth of amount in inland areas.

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1. Introduction

Biogas is a flammable mixture comprising CH_4 primarily, and produced by bacterial anaerobic fermentation of biomass waste resources, such as crops straw, livestock excrement or organic wastewater [1]. It can replace fossil energy to provide cleaning and alternated energy for farmer's daily life and agricultural production. It is a good way in solving the energy shortages for rural living and plays an important role in maintaining national energy security [2,3]. The residues produced from anaerobic fermentation can also be used as fertilizer for agricultural production [4]. Anaerobic fermentation can also effectively solve the rural non-point pollution caused by livestock excrement arbitrary discharge and crops straw messy stack, and reduce the greenhouse gases released into atmosphere. As the connection chain of livestock breeding, agricultural production and energy supplying, biogas is becoming one of the most common biomass energy products [5,6].

2. Current situation of biogas industrial development in China

China is one of the earliest countries to develop and utilize biogas. In 1930s, Luo Guorui manufactured the first biogas digester in China, which promoted Chinese household biogas development rapidly [7]. Currently, China has the largest quantity in using household biogas in the world. In 2008, the number of global household biogas digesters was about 35,000,000, of which China accounted for 87.14% [8]. At the end of 2010, the amount of household biogas digesters reached 38,508,000, the large and medium-scale biogas project was about 27,436, and the biogas production reached 14.1 billion m^3 [9]. Biogas has become an important part of advanced biomass energy in rural life, and the status in rural living energy consumption structure has enhanced gradually.

2.1. Household biogas

Household biogas refers to the normal temperature anaerobic fermentation system used by household as a unit. In the system, biogas is the main product, with animal feces and crop straw being raw materials, and the single-digester size is generally not more than 20 m^3 [10]. Though the household biogas digesters construction began in 1930s in China, the scale did not begin to develop until the late 1980s due to immature technology and incomplete management system. Especially after 2000, the Ministry of Agriculture of China has launched some promotion projects, such as *Energy Environmental Protection Project*, *Ecological Homestead Rich Peasant Project*, and *Biogas Construction National Bond Projects*, etc. Under the supporting of these policies, the amount of national household biogas digesters has increased rapidly (Fig. 1), with more than 1 million each year, and the average growth rate is about 15% each year. Household biogas has become the biggest biomass energy industry in China.

2.2. Biogas project

Biogas project is the anaerobic fermentation system by processing high concentration organic wastewater as raw materials to lower COD and BOD and produce biogas, and the digester capacity is generally more than 50 m^3 [11]. Biogas project includes farm biogas project and industrial organic wastewater biogas project. This study is concerned with the former. The construction of farm biogas project began in the early 1980s in China. *Chengdu Phoenix Mountain Horticultural farm* built the first Chinese biogas project in 1982 [12].In the middle 1990s, with the rapid development of scale livestock breeding, environmental pollution in farms has increasingly attracted attention and the amount of biogas project increased rapidly (Fig. 2). In 1996, the amount of large and medium-scale farm biogas projects was about 460, with total digester capacity of 1.36×10^5 m^3, and the biogas production reached 2.0×10^7 m^3, while in 2010, the number increased to 27,436,7.32×10^6 m^3, and 1.01×10^9 m^3 [9].

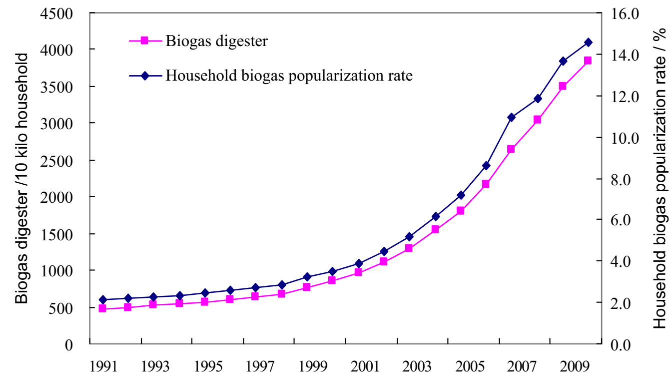


Fig. 1. Current situation of household biogas development in China from 1991 to 2010. Note: it is calculated based on 1996–2010 China's rural statistics [9].

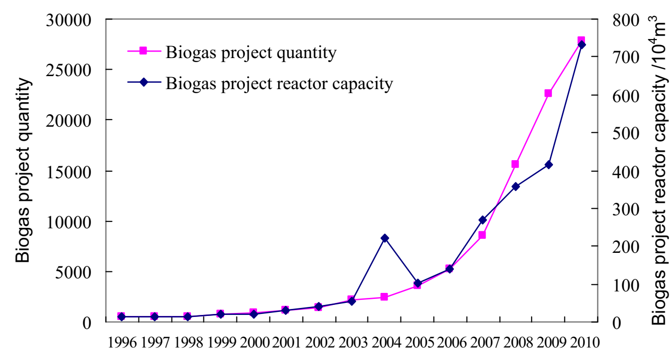


Fig. 2. Current situation of farm biogas project in China. Note: it was calculated based on 1996–2010 China's rural statistics [9].

3. Regional differentiation of biogas development in China

3.1. Appraise index

In current studies, the commonly used indicators are biogas production [13,14] and digesters amount [2,15], both of which are gross indicators, and generally used for describing the total quantity in single or multiple regions. In the study of general differences in different areas, there exists an issue of mixed criteria, which has a quite diversity in appraise indexes, such as land area and population size. In this study, biogas popularization rate was taken as evaluation index to avoid the problems of mixed criteria.

(1) The popularization rate of household biogas digester refers to the proportion of rural households with the construction of biogas digester to the total households. In this study, it is estimated as following:

$$\eta_i = p_{H-biogas}/P_{H-total}$$

where η_i is household biogas popularization rate, %; $p_{H-biogas}$ is the amount of household biogas digesters; $P_{H-total}$ is the amount of total households.

(2) Biogas project popularization rate is the ratio of farms with biogas projects to the total large-scale farms; it can be calculated as follows:

$$\eta_j = p_{F-biogas}/P_{F-total}$$

where η_j is biogas project popularization rate, %; $p_{F-biogas}$ is the amount of biogas projects; $P_{F-total}$ is the amount of large-scale farms.

According to '*livestock farm pollution control measures*', in this study, the large-scale farms refer to the livestock farms where annual breeding livestock or poultry is more than 500 pigs, 1000 sheep, 10,000 chickens, 100 cattle or the equal size of other livestock [16].

3.2. Household biogas

According to the geographical distribution map of household biogas popularization rate (Fig. 3), Chinese household biogas development has the following characteristics:

(1) The popularization rate of household biogas digesters in China presented an increasing tendency annually, and the national average popularization rate increased from 2.13% in 1991 to 14.59% in 2010.
(2) In the views of average annual growth rate of household biogas digesters popularization rate, it presented the features of rapid growth in western regions, steady development in central regions, slow growth in eastern coastal areas and rapid decline in typical developed areas (Fig. 4). From 1991 to 2010, the average annual growth rate of household biogas in 60% of the provinces (cities, districts) is above the national average (10.65%), of which the annual growth rates of household biogas digesters in Tibet, Ningxia and Xinjiang were 81.45%, 48.3% and 44.18%, respectively. The growth rate was more than 35% in Shanxi, Heilongjiang, Guizhou and Qinghai, but was below 10% in Hubei, Fujian, Shandong, Tianjin, Sichuang, Guangdong, Jiangsu. Moreover, it was less than 0 in Beijing, Shanghai and Zhejiang with the household biogas popularization rate decreased from 4.53%, 3.51% and 2.26% in 1991 to 0.46%, 0% and 1.14% in 2010.
(3) The popularization rate of household biogas digesters has significant regional differences, and is improved year by year. As a whole, two spatial differentiations were formed and divided by boundary of Inner Mongolia–Hebe–Henan–Anhui–Jiangxi–Hunan–Guangxi, etc. (Fig. 3). In the western and southern areas to the boundary, which account for 84.5% of Chinese land area with 67% of Chinese rural population, the household biogas popularization rate is high and growing rapidly. According to biogas popularization rate of 31 provinces (cities, districts) in China, it could be divided into five types (Table 1).

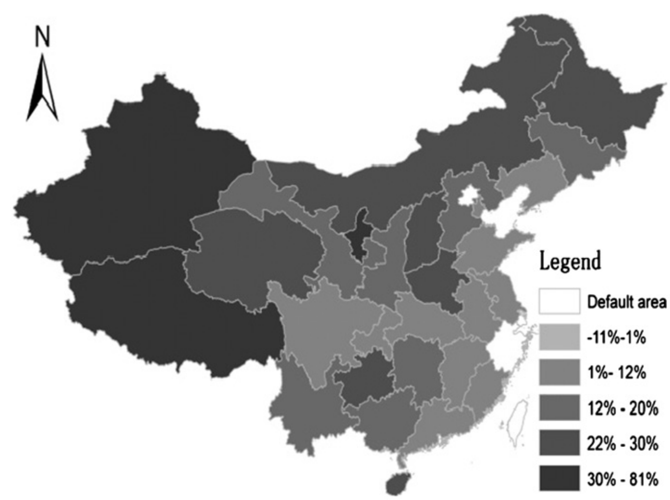


Fig. 4. Regional differences in average annual growth of household biogas popularization rate in China.

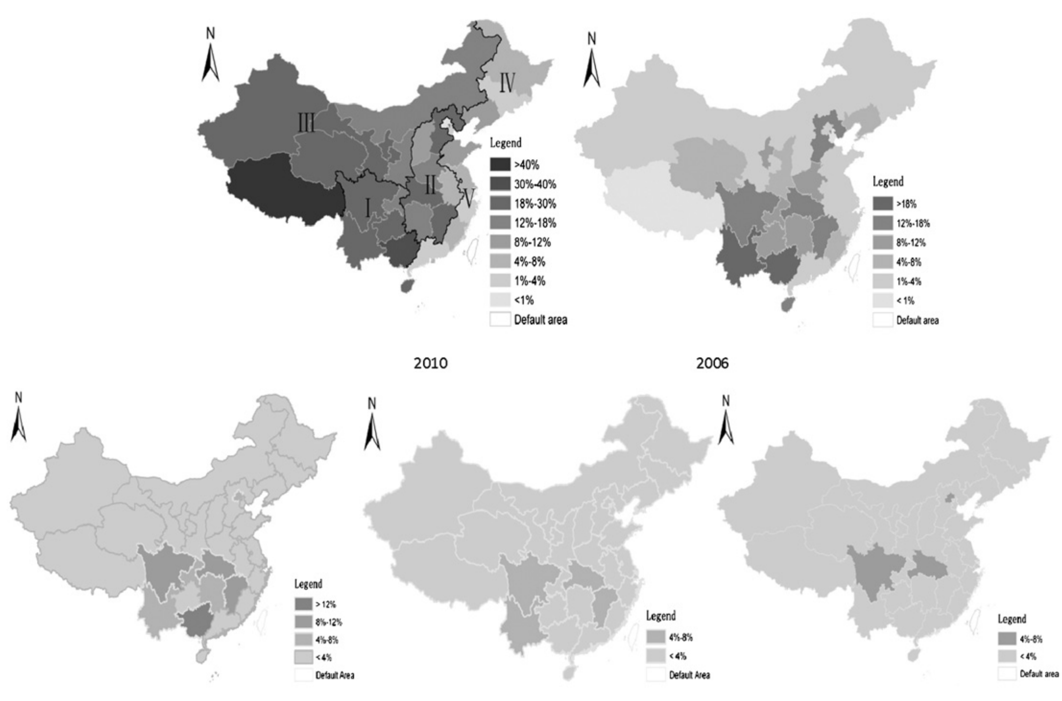


Fig. 3. Geographical distribution of household biogas popularization rate in China. Note: it was calculated based on 1996–2010 China's rural statistics [9].

Table 1
Area types of household biogas popularization in China.

Types	Areas	Regional characteristics
High popularization in Southwest area (i)	Including Sichuan, Yunnan, Guizhou, Guangxi, Hainan, and Chongqing, etc.	The biogas development started early, and popularization rate was in a leading position. In 2010, the amount of household biogas digesters reached 14,980,000, accounting for more than 38.9% of the national total; household biogas average popularization rate was about 21.8%, much higher than the national average.
Steady development in central area (ii)	Including Henan, Hubei, Hunan, Jiangxi, Hebei, Shanxi, Anhui, etc.	The number of household biogas digesters is large, which reached 14,764,000 in 2010, accounting for 38.34% of the national total. However, the average popularization rate is only about 16.07%, slightly higher than the national average.
Rapid growth in western area (iii)	Including Tibet, Xinjiang, Qinghai, Gansu, Shaanxi, Ningxia, Inner Mongolia, etc.	From 1991 to 2001, there was an average penetration rate of 1.5% in western area. After 2003, it has a rapid growth. The household biogas digesters reached 3,804,000 in 2010, and the average popularization rate increased to 18.6%.
Low popularization (iv)	Including Heilongjiang, Jilin, Liaoning, etc.	The biogas development started lately, and grows slowly. In 1991, the total amount was about 92,700, less than 2% compared to national amount, and the household biogas popularization rate was only 0.49%. In 2010, the total amount increased to 1,013,000, accounting for 2.6% of the national level, and the popularization rate was about 6.1%, only equal to 42% of the national average.
Low popularization in eastern coastal area (v)	Including Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Shanghai, etc.	Household biogas started early, but grows slowly. In 1991, the total amount was 1,239,200, accounting for 26.08% of the national total. However, it reached 3,896,000 in 2010, making up 10.12% of the national total and the average popularization rate was only 5.32%.

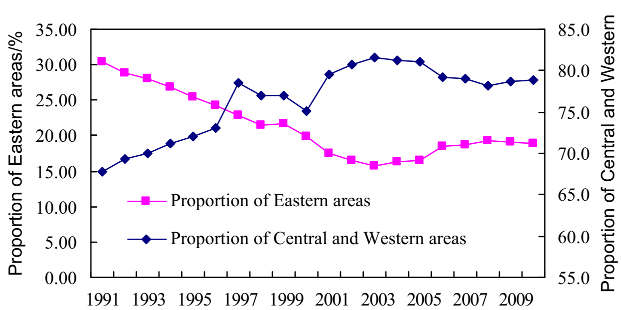


Fig. 5. Biogas development trend of Eastern and Western regions of China.

(4) The emphasis of household biogas development was shifting from Eastern areas to Western areas. With the rapid development of national household biogas, the amount of biogas digester has increased gradually in Eastern regions of China from 1991–2010, but the growth rate is below the national average. And the proportion of household biogas digesters amount in Eastern regions of China to national amount presented a downward trend (Fig. 5). In 1991, the amount of household biogas digesters was 1,448,700 in Eastern China, accounting for 30.49% of the national total. However, it reduced to 17.57% in 2001 and 15.69% in 2005. Correspondingly, the proportion of household biogas digesters to national total in the Central and Western regions of China increased from 67.8% in 1991 to 78.9% in 2010. Such changes are space reflects primarily resulting from national policy orientation, socio-economic factors and biogas technology.

3.3. *Farm biogas project*

As the Fig. 6 shows, the development of Chinese farm biogas projects having the following characteristics:

(1) The popularization of large and medium-scale biogas project in large scale livestock farms was increasing from 2001 to 2006, with the average annual growth rate of about 9.15%, but it increased to 21.53% from 2006 to 2010. Overall, the Chinese popularization rate of farm biogas project was low, and the national average was only 5.79% in 2010.

(2) Promotion scope of farm biogas project expands each year, and the amount of provinces with high popularization rate increases gradually. The areas without biogas project were in about 8 provinces (cities, districts) in China in 2001, which accounted for about 60% of the national land areas. And the popularization rate in 5 provinces (cities) including Shaanxi, Chongqing, Hubei, Jiangxi and Fujian was over 5%. In 2010, the areas without biogas project were just in Tibet and Shanghai, and the regions with popularization rate of more than 5% increased to 13 provinces. Among them, farm biogas project development in Zhejiang was the best, with popularization rate of 58.33%. And in Shanghai, the amount of biogas projects was 41 in 1996, the digester capacity was 38,300 m^3, and the biogas production was 9,913,400 m^3. But with the implementation of *Pinghu gas into Shanghai project* (1999), the opening of *East branch of West-East Gas Project* (2004), and the policy of *urban gas conversion presented by the government*, biogas consumption declined, Farm biogas projects decreased to 30 in number in 2001 and were withdrawn from Shanghai in 2006 (Fig. 7).

(3) Great regional differences exist in the popularization rate and growing trends of Chinese farm biogas projects, which are featured by scattered pattern. The areas with popularization rate of above 5.0% were mainly located in south regions to Yangtze River from 2001 to 2010. The amount of biogas project in Sichuan, Henan, Zhejiang, Hainan and Shandong grew rapidly, with the number increasing from 26, 36, 41, 12 and 37 in 2001 to 2390, 2545, 7240, 711 and 1242 in 2010, and the average annual growth rate was about 57.16%, 53.08%, 50.4%, 46.41% and 42.1%. From the views of popularization rate, a rapid growth was shown in Zhejiang, Hainan and Shandong which increased from 4.21%, 2.95% and 0.21% in 2001 to 58.33%, 43.22% and 1.63% in 2010. The amount of the running biogas projects increased gradually in the areas including Hubei, Anhui and Jiangxi. However, with the rapid development of livestock farms, biogas popularization rate has been reduced from 6.71%, 2.44%, and 7.21% in 2001 to 1.09%, 1.42% and 6.72% in 2010. As a whole, it can be concluded that development pattern was formed in the south

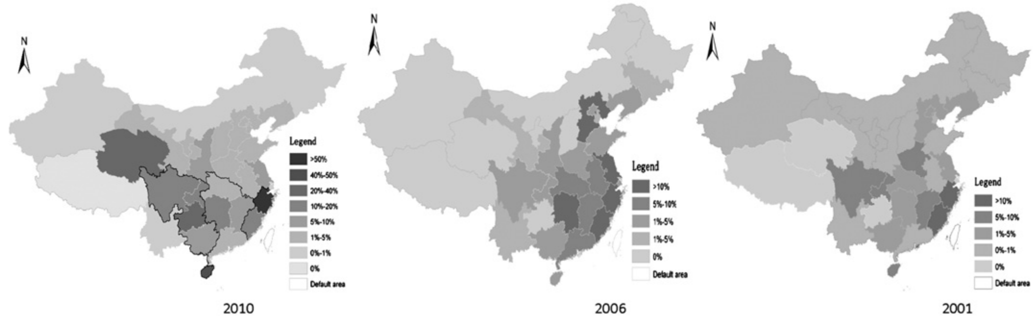


Fig. 6. Geographical distribution of large and medium-scale farm biogas project. Note: it was calculated based on 2001–2010 China's rural statistics [9] and China livestock Statistical Yearbook of 2002–2011 [17].

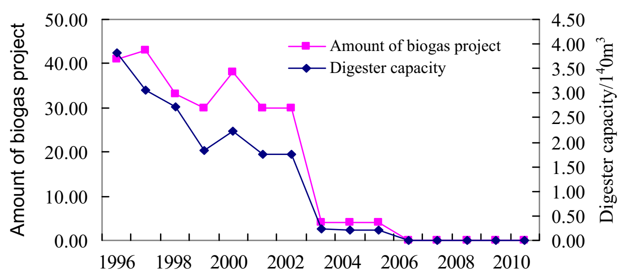


Fig. 7. Development of biogas project in Shanghai (1996–2010).

areas to Yangtze River, which consisted of the two-way growth of amount and popularization rate in southeast coast and southwest regions and the unidirectional growth of amount in inland areas.

(4) Fig. 8 indicates the development tendency of Chinese farm biogas project spreading from coastal to inland areas. The area with the amount of biogas project more than 100 was only Jiangsu province in 1996, but expanded to 5 provinces in 2001, 80% of which were located in the coastal areas. In 2006, the provinces where biogas projects were above 100 reached to 12, and increased to 21 in 2010, not only covering all the provinces of coastal area, but also including the inland provinces, such as Hubei, Anhui, Chongqing, Yunnan, Tianjin, shaanxi, Guizhou, Gansu, Shanxi, etc., which resulted in north–south distribution pattern by the boundary line of Liaoning–Hebei–Shanxi–Shaanxi–Gansu–Sichuan. And in the south to the demarcation line, there are 98.63% of large- and medium-sized running biogas projects and 94.5% of digester capacity.

4. Mechanism discussion of regional differentiation

Biogas development has obvious geographical differences in China. It may be affected by fermentation temperature, precipitation, biomass resources, economy, technological level and the traditions [14,18].

4.1. Household biogas

Chinese household biogas industry is mature and has higher popularization rate over the country. In the geographic distribution of biogas digesters popularization rate, policy guidance, regional economy and climate conditions have combined influences on the spatial distribution of household biogas in China. Generally, the area with policy as the leading impact factor is Tibet, and the areas influenced mainly by regional economic conditions are located in eastern coastal areas (including Shandong, Jiangsu, Zhejiang, Fujian, Shanghai, Guangdong and other provinces). The land area of Tibet and the coastal areas is less than 20% of total land area of China, with the total amount of household biogas digesters less than 10% of the national total. And 90% of household biogas digester distribution is affected by climatic conditions.

4.1.1. Climatic conditions

The relationship between distribution of household biogas digester and latitude was analyzed by regression analysis method.[1] The results showed that the popularization rate of Chinese household biogas digester was positively correlated with latitude, and the relevance gradually increased over time (Fig. 9). The reasons may lie in the fact that the biogas promotion largely depends on government support in early stages, and the influence of natural environment is weak. With the advancement of biogas digester popularization, biogas development is transformed from sociality steering to comprehensive phenomenon, and then the influence of natural environment is increasing with the main function of natural law. The correlation coefficient square R^2 of the popularization rate of Chinese household biogas and latitude reached 0.58 in 2010 by regression analysis.

4.1.2. Socio-economic conditions

The relationship between distribution of household biogas digester and longitude was analyzed by regression analysis method (Fig. 10). And the results showed that there were inconspicuous relationships between them in 1991, 1996 and 2001, but obvious in 2006 and 2010, of which the relationship curve presented semi-parabolic shape. And the correlation coefficient square R^2 was 0.6507 and 0.5706. The peak appeared at longitude of 103.5°and 102.12°, i.e. the position of Yunnan and Sichuan. The popularization rate was less than 1% in vicinity areas of longitude 120°, i.e. Shanghai and Zhejiang, Which was mainly influenced by terrain factors and economic conditions. In the Western regions of China, the land is mostly plateaus and mountains, the temperature is low, and the special climate characteristics make it difficult to ferment effectively. In 2003, the biogas development began to popularize in large scale under the support of *National biogas bond projects* and *Tibet-aid work*, and grew rapidly. In the southeast coastal areas, with better rural economy and suitable climate, the digesters popularized fast between 1991 and 1996. However, with further economic

[1] Analysis area does not include Tibet and Eastern coastal areas.

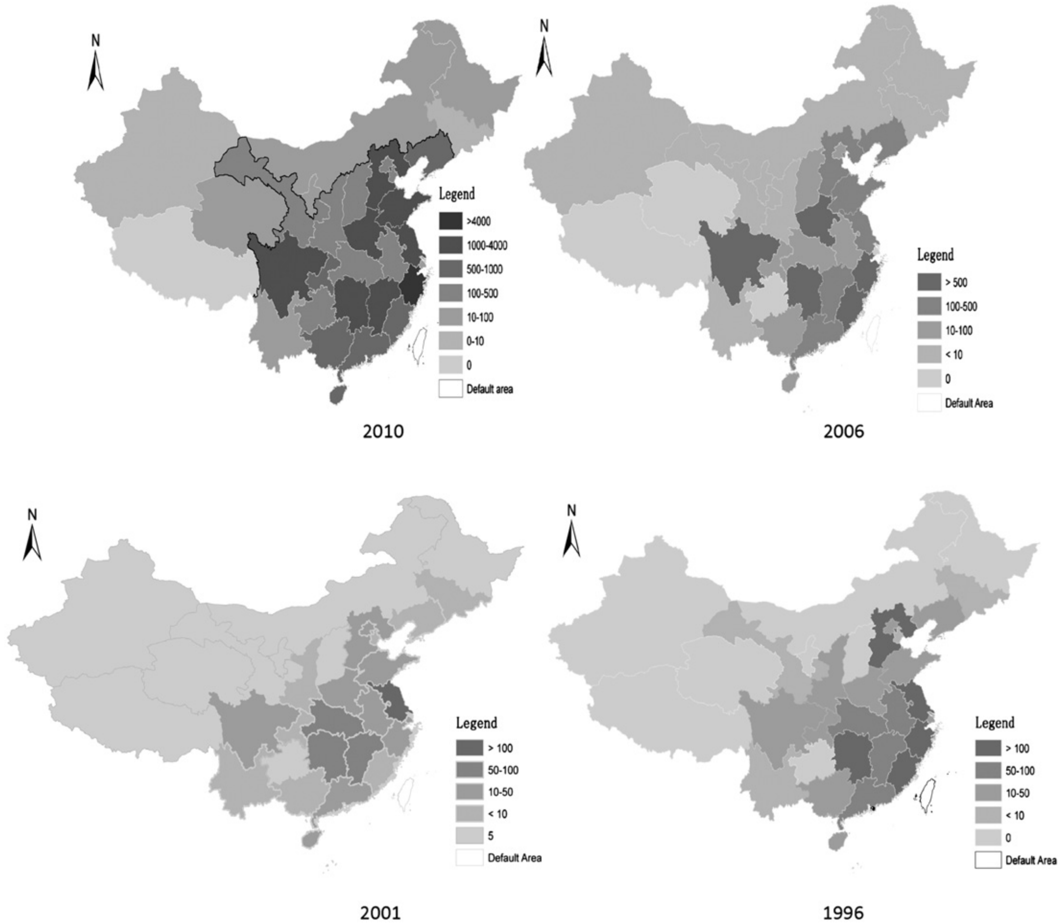


Fig. 8. Geographical distribution of farm biogas project running amount.

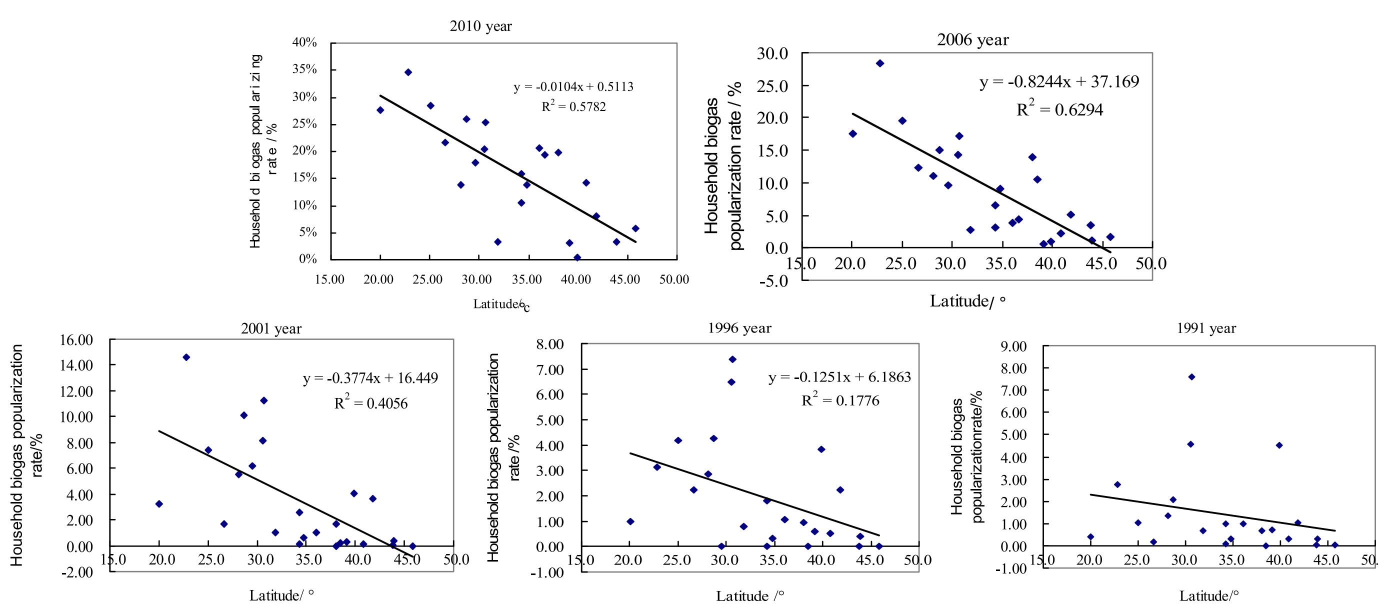


Fig. 9. Regression analysis diagram between Chinese household biogas popularization rate and latitude.

development, the popularized number of biogas digesters is decreasing annually due to the tedious process of biogas utilization and more farmers are willing to choose commercial gas. This also showed that in the case of high economic level, biogas is only a clean energy, while lacking convenience, therefore, technology and equipment of easier use of biogas are urgently demanded.

4.2. Farm biogas project

4.2.1. Raw material resources

Livestock breeding is prosperous in China. At the end of 2010, there were 1.22×10^8 of livestock, 4.65×10^8 of pigs, 2.85×10^8 of sheep, and 5.35×10^8 of poultry all over the country [17]. They

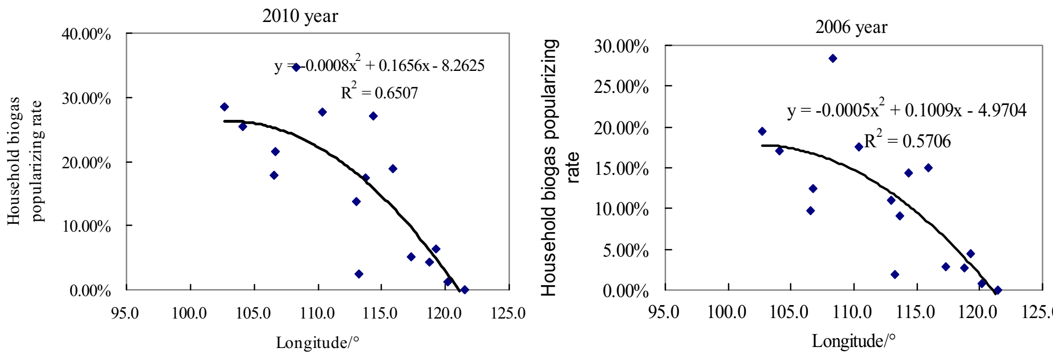


Fig. 10. Regression analysis diagram between Chinese household biogas popularization rate and longitude.

can produce 1.18×10^9 t (dry matter) of manure resources in breeding process, of which 4.32×10^8 t was produced from large-scale livestock farms, and the collectable resource reached to 2.80×10^8 t. If all these resources is utilized by anaerobic fermentation, 5.60×10^{10} m^3 of biogas will be produced. Currently, the utilization rate of the feces is less than 0.5%. Therefore, the raw material resources are not being the limited factor to biogas project development at present. The regression analysis, with farm livestock manure resources as independent variables and biogas popularization rate as dependent variable, showed that there was no correlation between manure resources and biogas popularization rate.

4.2.2. Climatic conditions

Based on the current technology level of biogas project construction, climatic conditions have little effect on biogas popularization in China, except Tibetan plateau and Northeast regions. The regression analysis, with latitude as independent variables and biogas popularization rate as dependent variable, showed that the correlation was not significant between latitude and biogas popularization rate. The reasons mainly lie in the fact that the construction of Chinese farm biogas projects started lately, which still stayed in primary phase and the general laws in geographical distribution has not yet been formed.

4.2.3. Economic conditions

Regional economy is supposed to be an important factor in the process of biogas project construction. It will cost 2 million Yuan to build a biogas digester with tank capacity of 1000 m^3. If installing the auxiliary power generation equipment, the unit construction cost is about 4000 Yuan/kW or more. The regression analysis, with per capita GDP as independent variables and biogas popularization rate as dependent variable, showed that there was no evident relation between them.

The raw material resources, climatic conditions and economic conditions are not the decisive factor in geographical distribution of biogas project in China, which is mainly due to the fact that biogas project promotion is still in the beginning stages, and fails to enter the industrialized phase. Thus, the development pattern is the external promotion mode, which does not follow the socio-economic law of industrial development and natural laws of industrial distribution temporarily.

Biogas project construction is an effective solution to solve the rural non-point pollution caused by optional discharge of livestock excrement and messy stack of crops straw and weeds. And it is also one of the important measures to improve village image and to construct environment-friendly society. Biogas project construction is an important task that is emphatically supported by the government. So currently, the dominant factor on Chinese biogas project development is policy guidance.

5. Conclusions

China is a large agricultural country, with 50.05% of the population living in rural areas. The construction of infrastructure in rural environment and improvement of farmers' living standards have been top important issues to the government. Biogas project construction is an important measure to solve the energy shortage in rural living, to mitigate rural non-point pollution, and to construct new socialist countryside. Governmental attention and policy support is the major driving force for the development of biogas in China. The government invested a total of 23.0 billion for biogas development from 2003 to 2010 [19]. Currently, the investment is turning its focus from infrastructure to management and services, from the household biogas to intensive biogas project. The development trend of Chinese biogas will continue to promote household biogas, and focus on the development of intensive industrial biogas. Household biogas development will be focused on the central and western regions in the long run, while large and medium-scale biogas projects will be gradually spread from the east coast to inland.

The government should understand the regional differences, identify the potential of biogas development, and distribute special funds scientifically in the process of biogas development. In this study, we analyzed the regional differentiation of household biogas and large and medium-scale farm biogas projects in 31 provinces (cities) of China with the popularization rate as appraise index, aiming to provide decision-making standards for the biogas industrial development planning and rural energy development planning. The main results are as follows:

(1) Chinese household biogas industry is mature and the popularization rate is high over the country. The biogas digester popularization rate can better reflect the features of regional differentiation. The popularization rate of household biogas digesters in China is increasing from 1991 to 2010, and presents significant regional differences among provinces and cities. It can be divided into five zones: high popularity in Southwest areas, steady development in Central areas, rapid growth in Western areas, low popularity in Northeast areas, and low popularity in Eastern coastal areas. The emphasis of household biogas development is shifted from Eastern areas to Western areas, which is mainly caused by the combined effects of climatic conditions and economic level.
(2) Construction of biogas project in China is still in the beginning stage of industrial development. The popularization rate in livestock breeding farms is relatively low, but it grows rapidly

increasing from 1.57% to 5.79% from 2001 to 2010, with average increasing rate of 13.94%. Great differentiation exits in popularization rate and growth trend of biogas projects among 31 provinces or cities of China, with 98.63% of running biogas projects and 94.5% of the digester capacity located in south areas to demarcation line constituted by Liaoning–Hebei–Shanxi–Shaanxi–Gansu–Sichuan. Development pattern has been formed in the south areas to the Yangtze River, which consists of two-way growth of amount and growth trend in southeast coast and southwest regions and unidirectional growth of amount in inland areas.

Acknowledgments

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